FEASIBILITY STUDY OF RENEWABLE ENERGY RESOURCES AND OPTIMIZATION OF ELECTRICAL HYBRID ENERGY SYSTEMS
Case Study for Islamic Azad University, South Tehran Branch, Iran

by

Farivar FAZELPOUR[a] and Nima SOLTANI[b*]

[a] Department of Energy Systems Engineering, Faculty of Engineering, Islamic Azad University-South Tehran Branch, Tehran, Iran
[b] Young Researchers and Elite Club, South Tehran Branch, Islamic Azad University, Tehran, Iran

Original scientific paper
DOI:10.2298/TSCI150902218F

Renewable energies are increasingly seen as the best solution to a growing global population demanding affordable access to electricity while reducing the need for fossil fuels. Country of Iran has vast untapped solar, wind, geothermal, and hydroelectric sources that hold the potential to meet domestic needs. Renewable energy is also essential to Iran as it will curb massive air pollution. In this paper economical and feasibility study of various hybrid systems are performed by using HOMER software model for supplying electricity to the Engineering Department of Islamic Azad University. For this study, annual electricity demand of the university is 1,174,935 kWh with a peak demand of about 331 kW, average wind speeds, based on hourly data during the period of eleven years (2000-2010), are between 3 to 5 m/s in all months of the year. For solar radiation, six models are evaluated to select the best model for estimation of the daily global solar radiation on a horizontal surface in the study location. Among these six models, $H/H_0 = a + b(S/S_0) + c(S/S_0)^2$ *is chosen as the most optimum model for estimating solar irradiation. The results indicate that among the three hybrid systems for fulfilling electrical energy needs, the wind/diesel/battery hybrid system with nine wind turbines (20 kW), one diesel generator (300 kW), 50 batteries, and 50 kW power converters with net present cost of $4,281,800 and cost of energy of 0.285 $/kWh is the most economically efficient hybrid system. (based on 2015 US dollar).*

Key words: *renewable energy, global solar radiation, hybrid systems, HOMER software*

Introduction

Generating electricity from renewable energy rather than fossil fuels offers significant public health benefits. The air and water pollution emitted by coal and natural gas plants is linked to breathing problems, neurological damage, heart attacks, and cancer. Replacing fossil fuels with renewable energy has been found to reduce premature mortality and lost workdays, and it reduces overall healthcare costs. Wind, solar, and hydroelectric systems generate electricity with no associated air pollution emissions. While geothermal and biomass energy systems emit some air pollutants, total air emissions are generally much lower than those of coal- and natural gas-fired power plants. In addition, wind and solar energy require essentially no water

* Corresponding author, e-mail: nima_soltani@yahoo.com

to operate and thus do not pollute water resources or strain supply by competing with agriculture, drinking water systems, or other important water needs. Fossil fuels are also a source of greenhouse gases emissions, leading to concerns about global warming if consumption is not reduced, and through the destruction of ozone layer. Hence, it is proposed that renewable energy resources as alternative sources of energies instead of fossil fuels in order to cope with greenhouse gasses and ozone depletion [1-3].

Although Iran's oil and natural gas resources are abundant, they will likely be exhausted by about the same time when renewable energies are expected to become the main sources of energy globally. Iran has huge potentials for increased use of renewable energy sources, which could create large economic benefits for the country. The development of renewable energy sources also enables Iran to produce and distribute electricity in rural and remote areas, which would play an important role in increasing the infrastructural development in these areas as well as increasing welfare while protecting environment and the health of the people. This is particularly important since the level of poverty in the areas with rich wind and solar radiation is rather high.

Wind and solar are the most important and viable renewable energy sources in Iran. It has been estimated that in 26 areas of the country, as much as 6500 MW electricity can be generated by wind turbines. Therefore, wind energy projects in Iran are well ahead of all other alternative renewable energy sources. There have also been some applications to develop solar energy in Iran, but given the vast resources, this area is still highly unexplored. Recently, Iran has specified new subsidies for increasing renewable energy usage [4]. In order to provide an increasing load demand, photovoltaic (PV)-wind hybrid systems are utilized as a substitute for standalone green energy systems [5]. PV-wind hybrid system provides electricity especially in rural places [5]. Askarzadeh [5] developed a novel discrete chaotic harmony search-based simulated annealing (SA) algorithm for optimal sizing of integrated system. For this application, three algorithms including chaotic search (CS), harmony search (HS), and SA were utilized in order to develop a new discrete chaotic HS-based SA algorithm (DCHSSA) [5]. The simulated results indicate that the DCHSSA algorithm's performance is more advanced than that of other methods [5].

Ma *et al.* [6] conducted a detailed feasibility study and techno-economic evaluation of a standalone hybrid solar-wind system with battery energy storage for a remote island. The solar radiation and wind data on this island in 2009 was recorded for this study. The HOMER software was employed to do the simulations and perform the techno-economic evaluation. Thousands of cases have been carried out to achieve an optimal autonomous system configuration, in terms of system net present cost (NPC) and cost of energy (COE). Moreover, the effects of the PV panel sizing, wind turbine sizing and battery bank capacity on the system's reliability and economic performance were examined. Finally, a sensitivity analysis on its load consumption and renewable energy resource was performed to evaluate the robustness of economic analysis and identify which variable has the greatest impact on the results. The results demonstrate the techno-economic feasibility of implementing the solar/wind/battery system to supply power to this island [6].

Khalilnejad and Riahy [7] performed a design and modeling of PV-wind hybrid system for the purpose of hydrogen production through water electrolysis. Actual data for weekly solar irradiation, wind speed, and ambient temperature of stratovolcano Sahand, Iran, were used for performance simulation and analysis of the system examined. The 10 kW alkaline electrolyze model, which produces hydrogen, was based on combination of empirical electrochemical relationships, thermodynamics, and heat transfer theory. The operation of this system is optimized using imperial competitive colony algorithm. The objective of optimization is to maximize hydrogen production, considering minimum production of average excess power. As for this result, it was clarified that the hybrid system is more useful for this study [7].

Paliwal *et al.* [8] proposes a novel probabilistic model for battery storage systems to effectively facilitate implementation of analytical technique for reliability assessment based of renewable energy sources (RES) incorporating battery storage. The proposed probabilistic battery state model comprises of multiple states of battery state of charge and probability associated with each state [8]. The developed model takes into account variable nature of RES and their corresponding effect on storage systems. In order to demonstrate the effectiveness of proposed analytical technique, reliability assessment studies were carried out for a hypothetical autonomous PV-wind-storage system located in city of Jaisalmer, Rajasthan, India. The results obtained were compared with Monte Carlo simulation in order to establish the superiority of proposed approach [8].

Kumar *et al.* [9] performed an biogeography based optimization (BBO) algorithm to optimize size of wind/PV hybrid energy system in rural areas. The BBO algorithm is utilized in order to assess optimum component sizing by reducing the total cost of hybrid system. In this study a diesel generator is utilized to provide continuous power supply to encounter the discontinuous nature of wind and solar reserves. Results show that the hybrid energy systems can deliver energy in a stand-alone installation with an acceptable cost. It is clear from the results that the proposed BBO method has exceptional convergence property, require less computational time and can avoid the shortcoming of premature convergence of other optimization techniques to obtain the better solution [9].

Agarwal *et al.* [10] developed a simulation model to determine the best size of hybrid PV-diesel-battery system to maintain an appropriate balance between the life cycle cost (LCC) and CO_2 emission from the system. Decision variables included in the optimization process are total area of PV arrays, number of modules of 600 Wp and batteries of 24 V and 150 Ah, diesel generator power, fuel consumption, and CO_2 emissions per day. The proposed method is applied to a residential colony of 135 houses in city of Moradabad, India. Simulation results indicate that a system with a PV penetration of 86.6% and a diesel fraction of 13.4% with a PV area of 1000 m^2, 472 batteries of 24 V and 150 Ah, and a diesel generator power of 11 kW is the best option having a minimum LCC of 976,329.46$ for 25 years, fuel consumption of 24.22 L per day and CO_2 emission of 62.99 kg per day [10].

Li *et al.* [11] provided a techno-economic feasibility study of an autonomous hybrid wind/PV/battery power system for a household in city of Urumqi, China, using HOMER simulation software in order to optimize a model and simulation approach. The hybrid wind/PV/battery system with 5 kW of PV arrays (72% solar energy penetration), one wind turbine of 2.5 kW (28% wind energy penetration), 8 batteries each of 6.94 kWh, and 5 kW sized power converters comprises an optimum hybrid system for the household. It reduces the total NPC about 9% and 11% compared with PV/battery and wind/battery power systems, which has a similar result for COE [11].

Rehman *et al.* [12] designed a wind/PV/diesel hybrid power system for a rural area in Saudi Arabia which is presently powered by a diesel power plant consisting of eight diesel generating sets of 1,120 kW each. The study found a wind-PV-diesel hybrid power system with 35% renewable energy penetration (26% wind and 9% solar PV) to be the feasible system with COE of 0.212 US$ per kWh. The system was able to meet the energy requirements (AC primary load of 17,043.4 MWh per year) of the village with 4.1% energy in excess. The annual contributions of wind, solar PV and the diesel generating sets were 4,713.7, 1,653.5, and

11,542.6 MWh, respectively. The proposed hybrid power system resulted in avoiding addition of 4,976.8 tons of GHG equivalent of CO_2 gas in to the local atmosphere of the village and conservation of 10,824 barrels of fossil fuel annually [12].

In another research project for rural electrification in Saudi Arabia, Shaahid *et al*. [13] studied the techno-economic evaluation of off-grid hybrid PV-diesel-battery power systems. This study examines the effect of PV/battery penetration on COE of different hybrid systems. The optimization results show that the number of operational hours of diesel generators decreases with increase in PV capacity. Furthermore, a study prospects of autonomous/stand-alone hybrid (PV + diesel + battery) power systems in commercial applications in arid climate regions [14] and techno-economic evaluation of off-grid hybrid PV-diesel-battery power systems for rural electrification in Saudi Arabia – a way forward for sustainable development [15]. Elhadidy and Shaahid [16] studied the decentralized/stand-alone hybrid wind-diesel power systems to meet residential loads of hot coastal regions. The simulation results demonstrate that the hybrid system consisting of seven 150 kW wind energy conversion systems, together with three days of battery storage, is needed to satisfy the predefined residential load, 3512 MWh, for a significant portion of the year. The findings of this work can be employed as a tool for assessing the optimum size of wind machine and for sizing of wind/diesel/battery energy systems for coastal. Shadih [17] investigated autonomous wind farms and solar parks and their feasibility for commercial loads in hot regions.

Kaabeche and Ibtiouen [18] developed an optimum sized model based on an iterative method for optimizing the capacity sizes of different stand-alone PV/wind/diesel/battery hybrid system constituents. The suggested model takes into consideration the hybrid system sub-models, the total energy deficit (TED), the total NPC and the energy cost (EC). The flow diagram of the hybrid optimal sizing model is also demonstrated. The optimization results show that a PV/wind/diesel/battery option is more economically viable compared to PV/wind/battery system or diesel generator (DG) only.

Maheri [19] discussed an optimal design of a standalone wind-PV-diesel hybrid system is a multi-objective optimization problem with conflicting objectives of cost and reliability. Uncertainties in renewable resources demand load and power modeling make deterministic methods of multi-objective optimization fall short in optimal design of standalone hybrid renewable energy systems. For two design scenarios, finding the most reliable system subject to a constraint on the cost and finding the most cost-effective system subject to constraints on reliability measures, two algorithms are proposed to find the optimum margin of safety. The robustness of the proposed design methodology is shown through carrying out two design case studies.

Adaramola *et al.* [20] investigated the possibility of using hybrid energy system for electricity generation in rural and semi-urban areas in the Northern part of Nigeria. At current diesel price of \$1.1/L and annual mean global solar radiation (GSR) of 6.00 kWh/m^2 per day, it was found that PV/generator/battery hybrid system is economically the most suitable option as a stand-alone electricity generating system in this location and other similar locations in the Northern part of Nigeria. The optimal simulation results indicate that the leveled COE for this hybrid energy system varies between \$0.348/kWh and \$0.378/kWh depending on the interest rate. These costs are lower than the cost of using diesel generator only (without battery) which varies between \$0.417 and \$0.423 per kWh. It was further observed that there is a significant reduction in emissions of GHG if a hybrid energy system is used instead of only a generator based energy system.

Wind-diesel-PV hybrid systems with battery storage are the most reliable systems for supply load demands. There is wide variety in the cost accounting systems around the world because the wind speed and solar radiations and fuel cost are mostly fluctuate from one place to another; for example, COE per kWh in Binalood city [21] and Kish Island [22] in Iran are $0.422/kWh and $0.348/kWh, respectively. For a village in Saudi Arabia [12] ($0.212/kWh), for remote area in Ethiopia [23] ($0.383/kWh), in Malaysian [24] ($0.282/kWh), in Urumqi [11] ($1.045/kWh).

In this paper, three different hybrid models are presented and comparisons were made in order to achieve the advanced model for city of Tehran. In addition, the available data of Azad University, South Tehran Branch, were utilized to fit the model as a novel application. Tehran is a capital of Iran and is located in latitude of 35°41'46" N, a longitude of 51°25'23" E and an altitude of about 1200 meters above sea level. Tehran has a semi-arid continental climate and spreads through southern hillsides of Alborz Mountain. The biggest environmental problem Iran currently faces is air pollution, especially in the capital city. Tehran's air pollution is made even worse by the city's geographic position. The city is hemmed in by mountains to the north, causing the increasing volume of pollutants to become trapped, hovering over Tehran when the wind is not strong enough to blow the pollution away. Hence, there is a conscious effort to increase the share of renewable resources in the country. Figure 1 indicates global capacity of solar [25] and wind power [26] per GW from 1996 through 2013. As shown in fig. 1, the solar and wind capacity has a great growth from 1996 to 2013.

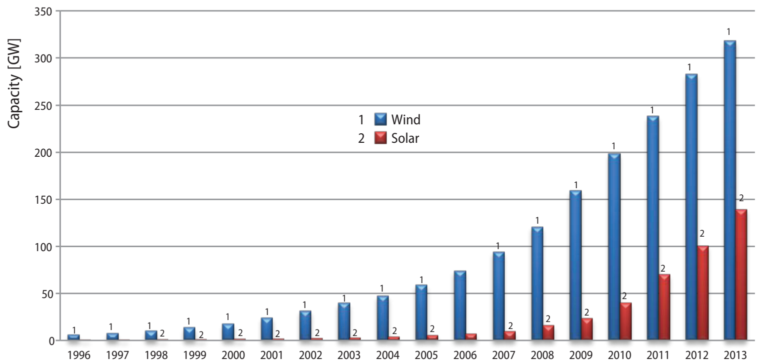

Figure 1. Global capacity of solar and wind power per GW from 1996 through 2013 [25, 26]

Iran is located in the middle east, between Iraq and Pakistan bordering the Gulf of Oman, the Persian Gulf, and the Caspian Sea. Latitude of Iran is 32 ^{0}N and longitude is 53 ^{0}E. Iran is semi-arid and has diversity of climates. Except for the northern and southern seashores, where high humidity is prevalent, humidity and rainfall are lower from north to south as well as from east to west. According to various studies total wind energy potential of Iran is approximately 60,000 MW, however, the total wind energy potential from the economical viewpoint is more than 18,000 MW.

Due to the high solar radiation in middle east countries such as Iran, solar energy is cost effective and widely used in domestic and industrial uses. Solar energy that can be utilized for thermal or electric generation (PV) is emission free and is considered to play a significant role in future energy development. The amount of solar irradiation in various parts of the world is different and the Earth's sunbelt regions offer great opportunities for solar business, as they feature very good solar irradiation levels.

Iran with 300 sunny days and average solar irradiation of 4.5-5.5 kWh/m^2 per day is one of the countries with high solar energy potential [27]. According to the studies by DLR, Germany, more than 60,000 MW solar-thermal power plants can be installed in an area of more than 2000 km^2. An area of 100×100 km^2 for installing solar-PV power plants is appropriate to produce the solar energy power approximately equivalent to the total power produced in Iran during 2010.

Data collection and site description

Tehran is a capital of Iran, the largest city of Iran and western Asia, and is the center of Tehran province. Tehran is 25th over populated cities of the world with the population of approximately 8.3 million. Tehran is located between mountain and desert and it spreads in the southern slopes of Alborz Mountain with an area of 730 km^2.

Load modeling for university

The Engineering Department of Islamic Azad University-South Tehran Branch was selected as a case study in this paper. The yearly total electricity load of the university, including engineering department, library, laboratories, and cafeteria, is 1,174,935 kWh. Figure 2 presents profile of monthly load of the university during a year. As indicated in the fig. 2, the maximum load demand is 331 kW which occurred during afternoon at about 13:00-14:00 p. m. in July. The reduction of load demand in March is because of Nowruz holidays in Iran.

Wind speed

Average wind speed data during period of eleven years (2000-2010) were provided by Tehran's meteorological station, and is shown in fig. 3 [28]. The wind speed data in Tehran's meteorological station are recorded every three hours in an altitude of 10 m above ground level. As shown in the fig. 3, the maximum monthly average wind speed is approximately 5 m/s in April. In general, wind speed varies between 3 to 5 m/s in all months of the year.

Solar radiation

The amount of solar radiation has a vital role in developing and planning the solar energy systems. In order to estimate solar radiation, a range of models are evaluated by researchers. Application of these models reduces necessity of installing expensive weather instruments in meteorological stations. Installation and operational costs of solar irradiation instruments and calibration systems are relatively high; therefore, the recorded data in Iran's meteorological stations and Renewable Energy Organization are not complete. Hence, in order to fill the data gap in this study, solar irradiation is also estimated by applying six different models (linear, exponential, quadratic, *etc*.). Additional weather input data (relative humidity, cloudiness, temperature and sunshine) are obtained from the Iran meteorological station. Comparison of these models output data with the ambient air observational data was done in order to select the optimum model for this study. Finally, the estimated solar irradiation was fed into the HOMER software.

Models

The utilization of solar energy is important in any region where there is a shortfall in electricity generation and distribution. The knowledge of the available solar radiation at a place is essential in selecting and designing suitable solar energy systems for that location. Unfortunately, solar radiation measurements are not widely available due to the high cost of the required equipment and the techniques involved. It has therefore become a common phenomenon to develop empirical equations of the Angstrom-type correlating the GSR on a horizontal

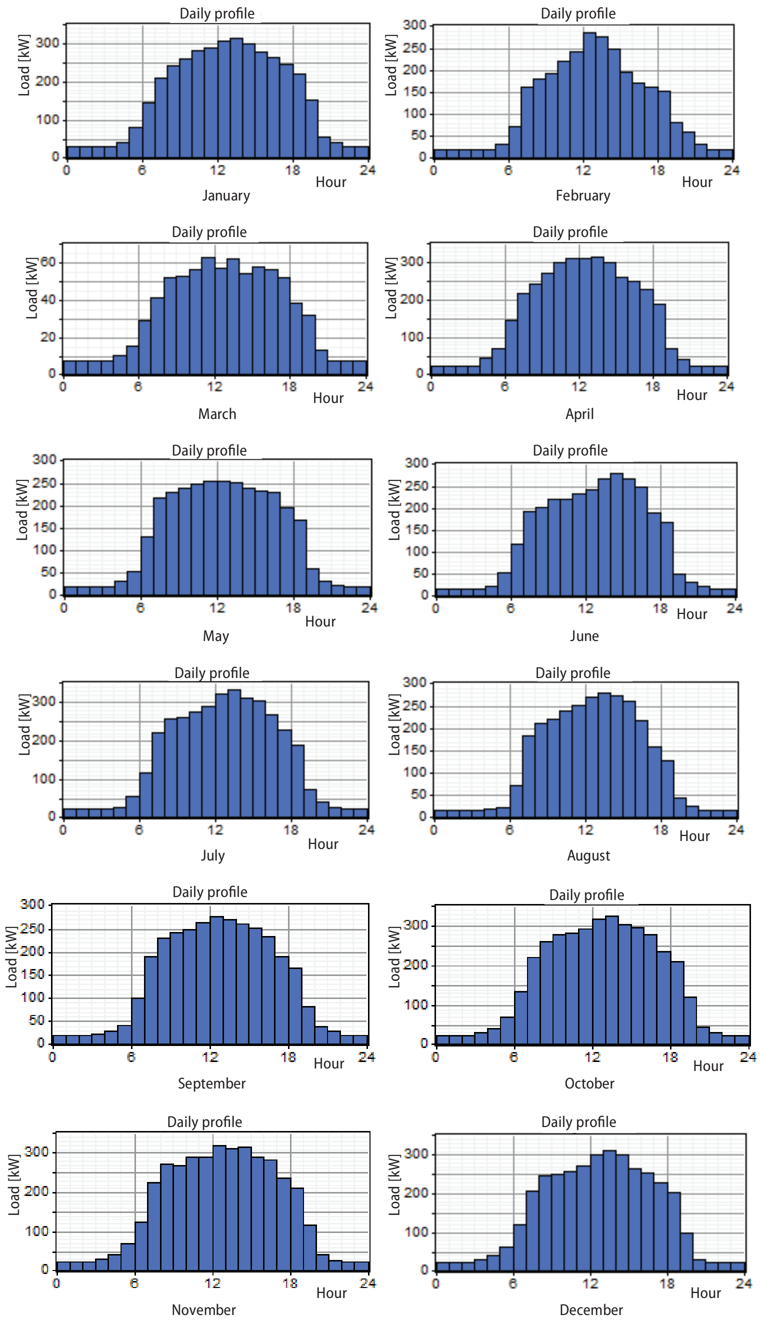

Figure 2. The daily profile of load demands per kWh for each month during a year

surface with the meteorological data at the location of interest, where solar radiation measurements are not carried out. Angstrom equation was developed by Angstrom, in 1924.

In eq. (1), H is monthly average daily global irradiation and, H_{cl} is average daily clear sky radiation, (S/S_0) is the proportion of sunny hours in a day to the hours of the day, a is

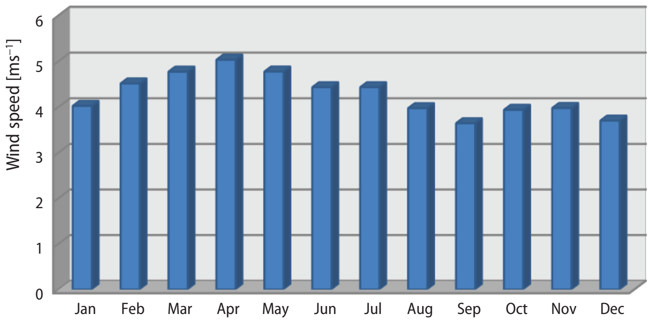

Figure 3. Wind speed per m/s for each month; data source [28]

related to climate condition of the region. One of the main disadvantages of the Angstrom equation is its intense relation with global daily solar radiation. Therefore, Angstrom equation is corrected by Prescott in 1940 and the Angstrom-Prescott equation is provided [29, 30]:

$$\frac{H}{H_{cl}} = a + (1-a)\frac{S}{S_0} \tag{1}$$

In eq. (2) H_0 and S_0 can be calculated theoretically and also experimental coefficients a and b can be obtained by applying the regression analysis with clarity index (H/H_0) and ratio of sunshine duration (S/S_0). The integrated daily extraterrestrial radiation on a horizontal surface (H_0) is estimated by the world meteorological organization and the solar constant (I_{SC} = 1367 W/m^2) can be obtained from the satellites data, eq. (3):

$$\frac{H}{H_0} = a + b\frac{S}{S_0} \tag{2}$$

$$H_0 = \frac{24}{\pi} I_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right)\left(\cos\varphi\cos\delta\sin w_s + \frac{2\pi w_s}{360}\sin\varphi\sin\delta\right) \tag{3}$$

Declination is the angular position of the Sun at solar noon (*i. e.*, when the Sun is on the local meridian) with respect to the plane of the equator, north positive, $-23.45 \le \delta \le 23.45$. Declination can be obtained by eq. (4) [31]:

$$\delta = 23.45\sin\left[\frac{360(n+284)}{365}\right] \tag{4}$$

The w_s is the solar hour angle that can be obtained by eq. (5) [31]:

$$w_s = \cos^{-1}\left[-\tan(\delta)\tan(\varphi)\right] \tag{5}$$

The S_0 is estimated by eq. (6) [32]:

$$S_0 = \frac{2}{15}w_s \tag{6}$$

The previous estimation shows that Angstrom coefficients can fluctuate for the different climate types. For instance, for Sweden climate the sum of a and b coefficients are equal to 1. Studies show that this amount increases with increase of latitude of the area. Glover and McCulloch [33] suggested that the eq. (7) representing a function of cosine's (latitude) for the latitude of less than 60^0 [34]:

$$\frac{H}{H_0} = 0.29\cos(\varphi) + 0.52\left(\frac{S}{S_0}\right) \tag{7}$$

In order to accurately estimate Angstrom-Prescott equation, several quadratic [35, 36], cubic [37, 38], logarithmic [39], exponential equations [39, 40] on the basis of solar radiation are recommended that are associated to clarity index (H/H_0), sunshine duration ratio (S/S_0), and other climate parameters. In this section six models are studied as they are listed in the tab. 1.

Table 1. The estimated models

1	$\frac{H}{H_0} = a + b\frac{S}{S_0}$
2	$\frac{H}{H_0} = 0.29\cos(\varphi) + 0.52\left(\frac{S}{S_0}\right)$
3	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2$
4	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\left(\frac{S}{S_0}\right)^2 + d\left(\frac{S}{S_0}\right)^3$
5	$\frac{H}{H_0} = a + b\left(\frac{S}{S_0}\right) + c\log\left(\frac{S}{S_0}\right)$
6	$\frac{H}{H_0} = a + bSH + c(T_{\max} - T_{\min})^2 + dSH^2 + eSH(T_{\max} - T_{\min})^2 + f(T_{\max} - T_{\min})^2 + gSH^3 + hSH^2(T_{\max} - T_{\min}) + iSH(T_{\max} - T_{\min})^2$

All regression coefficients in six equations are also calculated by SPSS software, and there listed in tab. 2. By employing the coefficients listed in tab. 2 and relevant calculations for obtaining solar irradiation, by using of MATLAB software, the estimated monthly average solar irradiation are listed in the tab. 3.

Table 2. Obtained regression coefficients

	Regression coefficients								
Model No.	*a*	*b*	*c*	*d*	*e*	*f*	*g*	*h*	*i*
1	0.1787	0.0701	–	–	–	–	–	–	–
2	02900	0.5200	–	–	–	–	–	–	–
3	0.1923	0.0088	0.0775	–	–	–	–	–	–
4	0.1717	0.2315	0.5236	0.4110	–	–	–	–	–
5	0.1815	0.0669	0.0012	–	–	–	–	–	–
6	0.2620	0.1298	0.0249	0.5784	0.0353	0.00216	0.6299	0.02026	0.002354

One critical aspect of this work is the selection of the most appropriate model for this study. This has been accomplished by evaluating error in the model output predication for each individual model. As indicated in the tab. 3, model 3 outputs agree very well with the observational solar radiation data, as it compared with all other models in all months of the year. Hence, we decided to use the model 3 with its estimates of solar radiation to feed into the HOMER software as an input data. Figure 4 represents monthly average daily solar radiation.

Table 3. Calculated and measured monthly averages of daily GSR [Wm^{-2}day^{-1}]

Month	Estimated by model No.						Measured
	1	2	3	4	5	6	
Jan.	1093	2496	1068	1080	1094	1207	994
Feb.	1356	3140	1357	1356	1356	1505	1377
Mar.	1755	4043	1759	1768	1764	1965	1450
Apr.	2201	5454	2188	2194	2201	2384	1849
May	2350	5313	2336	2362	2351	2606	2053
Jun	2652	7095	2641	2659	2653	2829	2474
Jul.	2631	7257	2633	2652	2624	2893	2754
Aug.	2430	6811	2447	2441	2429	2429	2812
Sept.	2072	5897	2097	2219	2071	2318	2112
Oct.	1605	4369	1601	1627	1609	1687	1395
Nov.	1144	2826	1149	1137	1139	1140	1563
Dec.	988	2357	990	989	989	1359	1133
Average	1868	4755	1856	1875	1871	2118	1830

Wind-PV-diesel hybrid power system with battery strong

The HOMER is a free software application developed by the National Renewable Energy Laboratory in the United States. This software application is used to design and evaluate technically and financially the options for off-grid and on-grid power systems for remote, stand-alone, and distributed generation applications. It allows considering a large number of technology options to account for energy resource availability and other variables. In this study, HOMER software is applied to simulate the wind/PV/diesel hybrid power system. The flow chart of energy diagram is shown schematically in the fig. 5. HOMER software will calculate the different permutations of possible designs based on the inputs provided and simulate the power system. The input data are briefly described in tab. 4.

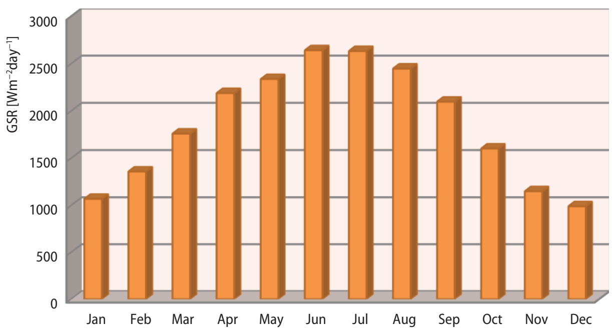

Figure 4. Monthly average daily solar radiation

Three different types of the diesel generators with capacity of 200, 250, and 300 kW are used in this study. A diesel generator is commonly designed to meet the peak power demand [22]. Peak load is of about 331 kW. However, maximum capacity of usable diesel generator in this case study is about 300 kW, mainly because the battery is used to supply the overload. From three diesel generators, only one generator is chosen. It should be noted that the reason for selecting the number of batteries, wind turbine, PV array with specific size selection, and converter, as listed in tab. 4, along with the calculations that were carried out several times with different input data is to obtain the best result and scope of the sizing and number of batteries for this case study. In addition, the HOMER software will provide error messages, in case of using inappropriate input data specifications.

Some of the basic control parameter: the system's lifetime is 25 years [20], the yearly profit rate is 22% [43], and the price of diesel fuel is $0.4 per liter [44].

Table 4. The HOMER software input data [21, 22, 41, 42]

Component	Model or size	Lifetime	Purchase cost	Replacement cost	Maintenance cost	Quantity
Diesel generator	200, 250, and 300 kW	15,000 h	1000 US$/kW	900 US$/kW	0.02 US$/h	1
Wind turbine	Generic 20 kW	15 year	15,000 US$/turbine	12,000 US$/turbine	50 US$/turbine per year	1, 5, 7, 9 and 11
PV module	10, 50, 100, 150, and 200 kW	20 year	3500 US$/kW	2500 US$/kW	30 US$/kW per year	–
Battery	Surrette 6CS25P (6V, 1156 Ah)	9645 kWh	1100 US$/kW	1000 US$/kW	10 US$/h	1, 5, 10, 15, 20, 25, 30, 35, 40, 45, 50 and 55
Power converter	1, 10, 15, 20, 25, 30, 35, 40, 45, 50, 55 and 60 kW	15 year	245 US$/kW	245 US$/kW	10 US$/kW per year	–

Note: Throughout the analysis, monetary units are presented in 2015 US$.

Optimization of the results

The HOMER energy modeling software is a powerful tool for designing and analyzing hybrid power systems, and it is used to achieve the objectives set in this study, including the function of analysis in finding the most cost-effective and most feasible system configurations. In this study, based on the input data, HOMER performs simulation on different system configurations to come out with the optimal selection based on cost of electricity or NPC. As summarized in the tab. 5, HOMER software suggests four systems. The first system is the most cost-effective system as compared with other systems. The fourth system (wind/PV/diesel hybrid system with battery power supply) is the most cost-effective system among 100 wind/PV/diesel/battery hybrid systems that analyzed by HOMER software. This has been selected as an optimum case to compare against other systems such as wind/diesel/battery. Different types of hybrid power systems are listed in tab. 5.

Wind/diesel/battery hybrid system

The results of the data analysis indicate that wind/diesel/battery hybrid system containing nine wind turbines, one diesel generator with 300 kW capacities, 50 batteries, and a power converter is the most cost-effective system as it compared with other systems listed in the tab. 5. In this system COE is $0.285 per kWh and NPC is $4,281,800.

Figure 6 shows nominal cash flows during 25 years for the wind/diesel/battery hybrid system and capital, replacement costs, salvage, operational, fuel costs during a lifetime of the system (25 years). As shown in fig. 6, the hybrid system`s capital cost is about $500,000 and must

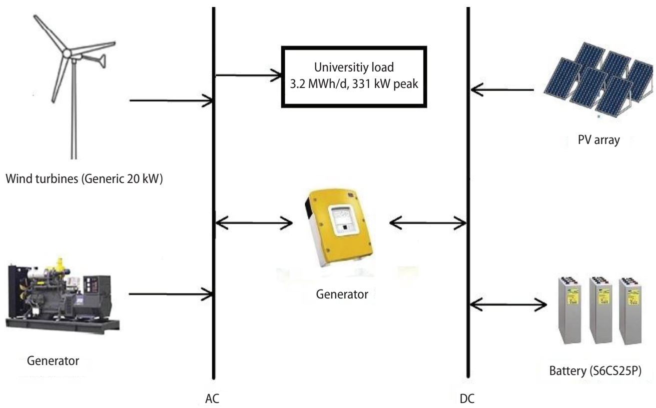

Figure 5. Schematic diagram of the flow chart of energy

Table 5. Different kinds of presented hybrid systems

System	PV module size [kW]	Wind turbine number	Diesel [kW]	Battery (S6C-S25P)	Conver-tor [kW]	Initial capital cost [$]	Operating cost [$/year]	TNPC [$]	Unit COE [$/kWh]
1	0	9	300	50	50	502,200	295,600	4,281,800	0.285
2	150	0	300	50	50	892,200	299,300	4,718,600	0.314
3	150	9	300	50	45	1,026,000	288,900	4,719,600	0.319

be expenditure at the start of its launching. The cost of fuel and operating is invariable during the 25 years, but the replacement varies in 25 years due to different lifetime for wind turbine, diesel, battery, and converter. The salvage cost can signify that selling some parts of the system which could work after the system lifetime and it is shown such as a returned diagram which is subtracted from capital cost of the system. For example, the lifetime of the selected wind turbine in this research, is 15 years and around that time the old wind turbine would be replaced with the new one and it can work through the end of year 30. Hence, at the end of 25th year (completion of the hybrid system lifetime) wind turbine can operate for additional five years, slightly greater than system lifetime. The HOMER software computes this time duration and subtracts it from the capital cost by the title of salvage cost. The cash flow for the wind/diesel/battery hybrid system is listed in tab. 6. As listed in the tab. 6, total cost of the generator is $3,974,800, the minimum total cost is related to power converter and total cost of the system is $4,281,800.

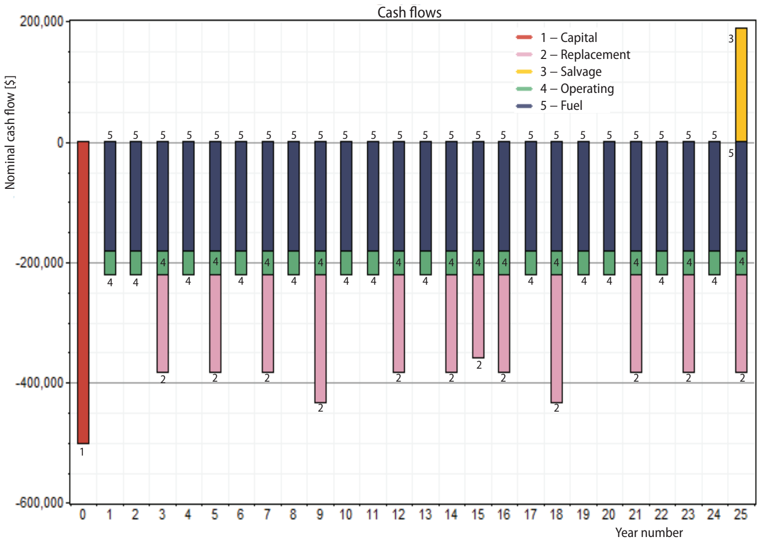

Figure 6. Nominal cash flow ($) during lifetime of the wind/diesel/battery hybrid system

PV/diesel/battery hybrid system

The PV/diesel system with battery storage source with total NPC $4,718,600 and COE $0.314 per kWh is the second power hybrid system as compared with three other recommended systems. The PV/diesel/battery hybrid system contains 150 kW PV arrays, one

Table 6. The summary of cash flow for the wind/diesel/battery hybrid system

Component	Capital [$]	Replacement [$]	O&M [$]	Fuel [$]	Salvage [$]	Total [$]
Generic 20kW	135,000	52,570	5,750	0	–9,790	183,500
Generator	300,000	885,670	513,810	2,306,800	–31,520	3,974,800
Surrette 6CS25P	55,000	47,720	6,390	0	–2,000	107,100
Converter	12,250	5,110	0	0	–950	16,400
System	502,250	991,080	525,950	2,306,800	–44,260	4,281,800

300 kW diesel generator, 50 batteries, and 50 kW power converter. Therefore, fig. 7 shows yearly cash flow summary for this system. According to this figure, the maximum amount of cost after fuel cost, $180,000 per year, is the replacement cost, $83,800 per year.

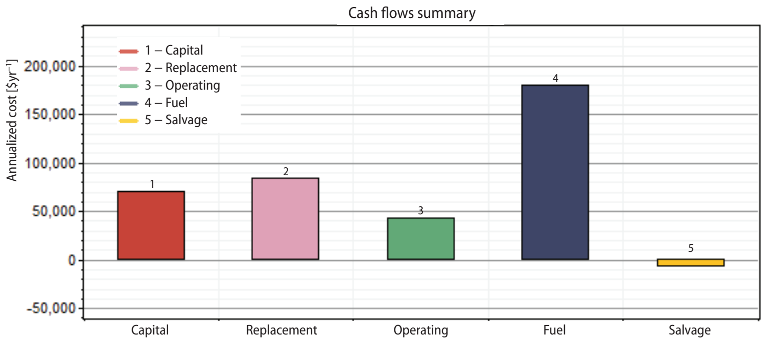

Figure 7. Yearly cash flow summary for PV/diesel/battery hybrid system

PV/wind/diesel/battery hybrid system

The PV/wind/diesel hybrid system containing a battery storage system, 150 kW PV arrays, 9 wind turbines, one 300 kW diesel generator, 50 batteries, and 45 kW power converter is the fourth economical and the third economical hybrid system. Total NPC and COE of the system are $4,719,600 and $0.319 per kWh, relatively. This system is the most reliable system among others. Figure 8 indicates average monthly electric produced by diesel generator systems, PV and wind turbines separately during a year. Also the system's costs are shown briefly in tab. 7. The maximum amount is related to diesel generator, $3,835,580, and the minimum amount is related to power converter $14,770.

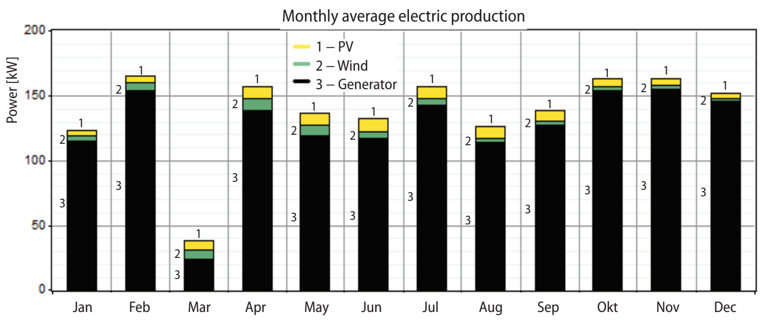

Figure 8. Average monthly electric produced by diesel generator systems, PV and wind turbines separately during a year

Table 7. The PV/wind/diesel/battery hybrid system's costs briefly

Component	Capital [$]	Replacement [$]	O&M [$]	Fuel [$]	Salvage [$]	Total [$]
PV	525,000	116,930	5,750	0	–65,530	582,150
Generic 20 kW	135,000	52,570	5,750	0	–9,790	183,540
Generator	300,000	835,410	501,780	2,202,000	–3,650	3,835,580
Surrette 6CS25P	55,000	45,930	6,400	0	–3,700	103,620
Converter	11,020	4,600	0	0	–860	14,770
System	1,026,020	1,055,400	519,670	2,202,000	–83,520	4,719,600

Environmental pollution

Local air pollutant emissions from fossil fuels and biomass combustion constitute the most important energy related impacts on human health. Ambient air pollution from the combustion of coal and traditional biomass has major health impacts and is recognized as one of the most important causes of morbidity and mortality worldwide. Hence, compared to fossil-based power generation, non-combustion-based renewable energy power generation technologies have the potential to significantly reduce regional and local air pollution and associated health impacts.

The most critical energy-related pollutant is air pollution in Iran's big cities. The rapid rate of urbanization due to rural migration to metropolitan areas, the rapid growth of vehicles and the associated consumption of petroleum, the use of older, poor burning vehicles, a poor public transportation system, the low price of petroleum products and a weak urban management are all contributing factors. Thus, contrary to the efforts to lower the level of air pollution, the number of cities recognized as being heavily polluted in terms of air quality, have increased.

In this section, the amount of pollution produced by the proposed systems is compared with each other, and the amount of penalty costs related to the pollution is evaluated as well. The amount of penalty cost of each tone of GHG produced by these systems is about $20 [22]. The annual amount of produced GHG for these three hybrid systems and standalone diesel generator system is shown in tab. 8 per kilogram.

Total amount of penalty costs in lifetime of the systems, for wind/diesel/battery hybrid, PV/diesel/battery, PV/wind/diesel/battery systems are $557,600, $555,690, and $529,720, respectively. However, if the university demand load supplies only standalone diesel generator system, total of penalty costs in life time of system is $639,600. Considering the penalty costs, the results indicate that using renewable energy resources instead of traditional systems would reduce the total costs.

Conclusions

Renewable energy technologies are one of the fastest growing technologies in the world, which will significantly contribute to economic growth in many countries in the near future. Furthermore, renewable energy such as wind, solar, geothermal, hydroelectric, and biomass provides substantial benefits for our climate, our health, and our economy. Country of Iran has vast untapped solar, wind, geothermal, and hydroelectric sources that hold the potential to meet domestic needs and boost export capacity. Renewable energy is also essential to Iran as it will curb massive pollution.

In this paper the probability of the hybrid systems by using wind, diesel and PV energy sources are economically analyzed and the most optimum model is represented for supplying the load demand of the Islamic Azad University, South Tehran Branch. Battery storage

Table 8. Annual amount of produced GHG for each system per kilogram

Emission type	Hybrid wind/diesel /battery system	Hybrid PV/diesel /battery system	Hybrid PV/ wind/diesel/ battery system	Diesel generator system
Carbon dioxide	1,088,000	1,085,000	1,034,000	1,240,500
Carbon monoxide	2,530	2,500	2,400	3,000
Unburned hydrocarbons	295	290	280	440
Particulate matter	190	185	180	280
Sulfur dioxid	2,000	1,900	1,880	3,500
Nitrogen oxides	22,200	21,500	20,700	31,500

sources are utilized in order to increase the reliability of the studied systems. The key results of the study are summarized:

- In this case study, assuming solar irradiation is not recorded for a long period of time for estimating solar radiation, six models are analyzed for obtaining the required input data. Among these six models, $H/H_0 = a + b(S/S_0) + c(S/S_0)^2$ with the average solar irradiation of 1856 W/m^2 per day is chosen as the most optimum model for estimating solar irradiation.
- Wind/diesel/battery hybrid system with NPC of $4,281,800 and COE of $0.285 per each kW is chosen as the most economic hybrid system as compared with other systems. This system contains nine wind turbines (20 kW), one diesel generator (300 kW), 50 batteries, and 50 kW power converters.
- The second economic system suggested by HOMER software is PV/diesel/battery hybrid system that contains 150 kW PV arrays, a diesel generator (300 kW), 50 batteries, and 50 kW power converters. The COE and NPC of this system are 0.314 $/kW and $4,718,600, respectively.
- The third economic system is PV/wind/diesel/battery system with COE and NPC of 0.319 $/kW and $4,719,600. This system is the third hybrid system and also the most reliable system among others. It contains 150 kW PV arrays, nine wind turbines (20 kW), 50 batteries, and 45 kW power converters.
- Total amount of penalty costs in lifetime of the systems, for wind/diesel/battery hybrid, PV/diesel/battery, PV/wind/diesel/battery systems are $557,600, $555,690, and $529,720, respectively. These amounts are less $82,000, $83,910, and $109,880, respectively, than when the university load supply by standalone diesel generator system.
- The cost that the Iranian government pays to purchase electricity from private power plants is 0.3 $/kW (9000 Rials/kW with *Rials as the local currency*), with consider penalty costs for three study systems, generating electricity by third hybrid power systems can be found to be economically than the local electricity price.

Acknowledgment

The authors thank the research center of Islamic Azad University–South Tehran Branch for supporting this research project (No. B/16/752).

References

[1] Oyedepo, O. S. with *et. al.*, Analysis of Wind Speed Data and Wind Energy Potential in Three Selected Locations in South-East Nigeria, *International Journal of Energy and Invironmental Engineering*, *3* (2012), 7, pp. 1-11
[2] Fazelpour, F., *et. al.*, Wind Resource Assessment and Wind Power Potential for the City of Ardabil, Iran, *International Journal of Energy and Environmental Engineering*, *6* (2015), 4, pp. 431-438

[3] Fazelpour, F. *et. al.*, Assessment of Wind Energy Potential and Economics in the North-Western Iranian Cities of Tabriz and Ardabil, *Renewable and Sustainable Energy Reviews*, *45* (2015), May, pp. 87-99
[4] Sawin, J. L., Renewables 2014 Global Status Report, Renewable Energy Policy Network for the 21st Century, Paris, 2014, pp. 1-21
[5] Askarzadeh, A., A Discrete Chaotic Harmony Search-Based Simulated Annealing Algorithm for Optimum Design of PV/Wind Hybrid System, *Solar Energy*, *97* (2013), Nov., pp. 93-101
[6] Ma, T. with *et. al.*, A Feasibility Study of a Stand-Alone Hybrid Solar–Wind–Battery System for a Remote Island, *Applied Energy*, *121* (2014), May, pp. 149-158
[7] Khalilnejad, A., Riahy, G.H., A Hybrid Wind-PV System Performance Investigation for the Purpose of Maximum Hydrogen Production and Storage Using Advanced Alkaline Electrolyzer, *Energy Conversion and Management*, *80* (2014), Apr., pp. 398-406
[8] Paliwal, P., *et. al.*, A Novel Method for Reliability Assessment of Autonomous PV-Wind-Storage System Using Probabilistic Storage Model, *International Journal of Electrical Power & Energy Systems*, *55* (2014), Feb., pp. 692-703
[9] Kumar, R., *et. al.,* Economic Analysis and Power Management of a Stand-Alone Wind/Photovoltaic Hybrid Energy System Using Biogeography Based Optimization Algorithm, *Swarm and Evolutionary Computation*, *8* (2013), Feb., pp. 33-43
[10] Agarval, N., *et al*., Optimization of Grid Independent Hybrid PV–Diesel– Battery System for Power Generation in Remote Villages of Uttar Pradesh, India, *Energy for Sustainable Development*, *17* (2013), 3, pp. 210-219
[11] Li, C., *et. al.*, Techno-Economic Feasibility Study of Autonomous Hybrid Wind/PV/Battery Power System for a Household in Urumqi, China, *Energy*, *55* (2013), June, pp. 263-272
[12] Rahman, S. *et. al.*, Feasibility Study of a Wind-PV-Diesel Hybrid Power System for a Village, *Renewable Energy*, *38* (2012), 1, pp. 258-68
[13] Shaahid, S. M., *et. al.*, Review of Economic Assessment of Hybrid Photovoltaic-Diesel-Battery Power Systems for Residential Loads for Different Provinces of Saudi Arabia, *Renewable and Sustainable Energy Reviews*, *31* (2014), Mar., pp. 174-181
[14] Shaahid, S. M, Elhadidi, M. A., Prospects of Autonomous/Stand-Alone Hybrid (Photovoltaic + Diesel + Battery) Power Systems in Commercial Applications in Hot Regions, *Renewable Energy, 29* (2004), 2, pp. 165-177
[15] Shaahid, S. M, El. Amin, I., Techno-Economic Evaluation of Off-Grid Hybrid Photovoltaic-Diesel-Battery Power Systems for Rural Electrification in Saudi Arabia-A Way Forward for Sustainable Development, *Renewable and Sustainable Energy Reviews*, *13* (2009), 3, pp. 625-633
[16] Elhadidi, M.A, Shaahid, S. M, Decentralized/Stand-Alone Hybrid Wind-Diesel Power Systems to Meet Residential Loads of Hot Coastal Regions, *Energy Conversion and Management, 46* (2005), 15-16, pp. 2501-2513
[17] Shahid, S. M, Review of Research on Autonomous Wind Farms and Solar Parks and Their Feasibility for Commercial Loads in Hot Regions, *Renewable and Sustainable Energy Reviews*, *15* (2011), 8, pp. 3877-3887
[18] Kaabeche, A., Ibtiouen, R., Techno-Economic Optimization of Hybrid Photovoltaic/Wind/Diesel/Battery Generation in a Stand-Alone Power System, *Solar Energy*, *103* (2014), May, pp. 171-182
[19] Maheri, A., Multi-Objective Design Optimisation of Standalone Hybrid Wind-PV-Diesel Systems under Uncertainties, *Renewable Energy*, *66* (2014), June, pp. 650-661
[20] Adaramola, M.S. *et. al.* Assessment of Decentralized Hybrid PV-Diesel Power System for Applications in Northern Part of Nigeria, *Energy for Sustainable Development*, *19* (2014), Apr., pp. 72-82
[21] Asrari, A., *et. al.*, Economic Evaluation of Hybrid Renewable Energy Systems for Rural Electrification in Iran – A case study, *Renewable and Sustainable Energy Reviews*, *5* (2012), 16, pp. 3123-3130
[22] Fazelpour, F. *et. al.*, Feasibility of Satisfying Electrical Energy Needs with Hybrid Systems for a Medium-Size Hotel on Kish Island, Iran, *Energy*, *73* (2014), Aug., pp. 856-865
[23] Bekele, G., Palm, B., Feasibility Study for a Standalone Solar-Wind-Based Hybrid Energy System for Application in Ethiopia, *Applied Energy*, *87* (2010), 2, pp. 487-495
[24] Lau, K. Y. *et al.,* Performance Analysis of Hybrid Photovoltaic/Diesel Energy System under Malaysian Condition, *Energy, 35* (2010), 8, pp. 3245-3255
[25] ***, From Wikipedia the Free Encyclopedia, Wind Power, http://en.wikipedia.org/wiki/Solar_power
[26] Global Wind Energy Council (GWEC) Global wind statistics, Brussels, Belgium, 2014
[27] ***, Iranian Renewable Energy Organization (SUNA) Tehran, Iran, <http://www.suna.org.ir/fa/sun/potential

[28] ***, Iran Meteorological Organization, http://www.weather.ir
[29] Bakirci, K., Models of Solar Radiation with Hours of Bright Sunshine: A Review, *Renewable Sustainable Energy Rev.*, *13* (2009), 9, pp. 2580–2588
[30] Suehrcke, H., On the Relationship between Duration of Sunshine and Solar Radiation on the Earth's Surface: Angstrom's Equation Revisited, *Solar Energy*, *68* (2000), 5, pp. 417–425
[31] Cooper, P. I., The Absorption of Radiation in Solar Stills, *Solar Energ*y, *12* (1969), 3, pp. 313–331
[32] Iqbal, M., *An Introduction to Solar Radiation*, The University of British Columbia, Vancouver, Canada, 1983
[33] Glover, J., Mc Gulloch, J., The Empirical Relation Between Solar Radiation and Hours of Sunshine, *Q J Royal Met Soc*., *84* (1958), 360, pp. 172-175
[34] Tymvios, F. S., *et. al.*, Comparative Study of Angstrom's and Artificial Neural Networks' Methodologies in Estimating Global Solar Radiation, *Solar Energy*, *78* (2005), 6, pp. 752-762
[35] Aksoy, B., Estimated Monthly Average Global Radiation for Turkey and its Comparison with Observations, *Renewable Energy*, *10* (1997), 4, pp. 625-633
[36] Tasdemiroglu, E., Sever, R., An Improved Correlation for Estimating Solar Radiation from Bright Sunshine Data for Turkey, *Energy Conversion and Manage.*, *31* (1991), 6, pp. 599–600
[37] Bahel, V. *et. al.*, A Correlation for Estimation of Global Solar Radiation, *Energy*, *12* (1987), 2, pp. 1341-1355
[38] Tahran, S., Sari, A., Model Selection for Global and Diffuse Radiation Over the Central Black Sea (CBS) Region of Turkey, *Energy Conversion and Manage.*, *46* (2005), 4, pp. 605-613
[39] Rensheng, C., *et. al.*, Validation of Five Global Radiation Models with Measured Daily Tada in China, *Energy Conversion and Management, 45* (2004), 11-12, pp. 1759-1769
[40] Togrul, I. T., Togrul, H., Global Solar Radiation over Turkey: Comparison of Predicted and Measured Data, *Renewable Energy*, *25* (2002), 1, pp. 55-67
[41] Guler, O., *et. al.*, Feasibility Analysis of Medium-Sized Hotel's Electrical Energy Consumption with Hybrid Systems, *Sustainable Cities and Society*, *9* (2013), Dec., pp. 15-22
[42] Fazelpour, F., *et. al*., Economic Analysis of Standalone Hybrid Energy Systems for Application in Tehran, Iran, *Proceedings*, 6th International Conference on Hydrogen Production, Oshawa, Ont., Canada, 2015
[43] ***, Central Bank of the Islamic Republic of Iran. 2015, http://www.cbi.ir/simplelist/1493.aspx
[44] ***, Iranian Management Fuel, 2015, (in Persian), http://hamsu.ir/Portal/Home/

Paper submitted: September 2, 2015
Paper revised: November 11, 2015
Paper accepted: December 10, 2015